HIGH-RESOLUTION TOTAL STREAM POWER ESTIMATES FOR THE COTTER RIVER, NAMADGI NATIONAL PARK, AUSTRALIAN CAPITAL TERRITORY.

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INTRODUCTION

Fluvial form and behaviour vary as a function of position among the numerous variables within a landscape. Channel gradient, degree of channel confinement, catchment hydrology and flood history, sediment character and supply, vegetation and human impacts to some degree all control stream form and behaviour. Bagnold (1966) adopted stream power as a theoretical basis for evaluating bedload transport. Since, it has been widely used to better understand such form and behavioural characteristics, in particular channel patterns and meander dynamics (Ferguson 1981) and changes induced as a result of human intervention (Brookes 1988). Stream power has also been used as a factor to delineate riverbed processes, notably when braiding has taken place (Van den Berg 1995).

Stream power is the energy available to transport sediment. Knighton (1999) defined the origin of the energy as coming from potential or position energy and as the water flows downslope, that energy is converted into the kinetic form. Here it is used to perform erosional and transportational work once a critical threshold determined has been reached. *Stream power* per unit length of channel (W m^{-1}) is defined as follows:

(1) $$\Omega = \gamma Q s$$

where γ is the specific weight of water (= 9810 Nm^{-3}), Q is the water discharge (m^3s^{-1}), and s is the energy slope (mm^{-1}), which may be approximated by the slope of the channel bed. Stream power is an expression of the rate of energy expenditure or flow strength at a given point in a river system.

Limits on contiguous discharge and slope data meant that earlier approaches of total stream power calculations relied on point locations to typify longitudinal trends (Nanson & Hean 1985, Lawler 1992, 1995, Magilligan 1992, Leece 1997, Knighton 1999). With the increasing availability and refinement of geographic information systems (GIS) and digital elevation models (DEM), detailed spatial analysis throughout the plethora of variables within the fluvial landscape is now feasible. Such tools have successfully modelled stream power at the mid-sized catchment scale (Reinsfelds *et al*. 2004, Jain *et al*. 2005) to the continental scale (Finlayson *et al.* 2002; Finlayson & Montgomery 2003) with confident correlations to real world values. However, attempts to model stream power at the small catchment scale have been unsuccessful.

LiDAR- (Light Detection And Ranging or Laser Radar) sourced elevation models are currently capable of producing DEMs to pixel resolutions of 1 m^2. DEMs used in previous studies relied on resolutions of 25 m^2 to 1 km^2 or greater to model various parameters including elevation, slope, and stream power (Riensfeld *et al.* 1999, Finlayson *et al*. 2002, Finlayson & Montgomery 2003). While the resolutions produce meaningful results for the longer reach scale, Finlayson & Montgomery (2003) found that the grid size selected has an effect on data as slopes tend to decrease with increasing grid size, drainage basins tend to be larger and stream length decreases significantly. This reflects decreasing sample points with decreasing resolution causing a bias in the regression. This translates to a decrease in estimates of the magnitude of stream power values. Pixel sizes to 1 m^2 permit the detailed modelling of the important small-scale changes in fluvial and geomorphic variables as good estimates of slope, catchment area and stream length are achieved.

In this study, 1, 5, and 10 m Lidar derived DEMs are used and comparisons are made of each on a 34 km reach of the Cotter River. Comparisons are made between each of each to gain an understanding of the problem of grid scale and its effect on the modelling of complexity down the river profile.

REGIONAL SETTING

The Cotter River catchment is the principle water supply catchment for the city of Canberra within the Australian Capital Territory. Running south to north along a fault set in Ordovician metasediments and Silurian granites, this upper section of the catchment falls from 1781 m to 889 m (1910 m on a tributary) at the base of the Corin Dam water supply reservoir wall. Rainfall in the catchment is roughly 935 mm/yr and the catchment spans approximately 194 km^2.

In: Roach I C. ed. 2005. *Regolith 2005 – Ten Years of CRC LEME.* CRC LEME, pp. 338-343.

The catchment is unusually characterised by being free of major land use change. Since the proclamation as water supply catchment in the early 1900s, the area has been recognised for the integrity of its natural values and now enjoys national park status. Various channel forms exist along the catchment's length. Headwater swamps/alluvial valley fill deposits are common, often with undefined channels. In some instances channels are incised to bedrock or basal cobble armour. Immediately downstream of the headwater areas, channel slope increases (Figures 1 and 2) causing the transport zone typical of many mountainous catchments (Schumm 1977, Montgomery & Buffington 1997). The transitory depositional zone occurs in the reaches with low slope. Here, the stream is often incised to bedrock but occasionally supported by sediments in the lower energy reaches. Valley fills are often wide typically up to 300 m with vegetation dominated by *Poa* tussock grasses on the fills and channels are often lined with heath or woodland.

METHODS

Discharge and slope are the two variables required for the total stream power equation (Equation 1). Slope values are calculated from the DEM in degrees using the slope function within the spatial analysis extension of ArcGIS version 9. The resulting slope grid was then divided by 100 to gain slope in m/m. The calculation of the discharge grid requires catchment area grids and discharge data. For each cell, catchment area is calculated using the flow accumulation grid. Flow accumulation represents the upstream area of a grid. Therefore, in a 1 m grid, flow accumulation is also upstream catchment area in m^2. For the 5 and 10 m grids, the square of each grid cell is calculated, resulting in a reasonable estimate of catchment area for each cell on the grid in m^2. Problems arising from the neglected measurement of diagonally contiguous pixels are considered negligible.

Discharge records are derived from two permanent gauging stations: Cotter River at Gingera (410730); and, the Licking Hole Creek Station (410776), having respectively 50 and 20 year records. In May of 2004, discharge measurements were made for every tributary of the Cotter River and downstream of each junction. An area-discharge relationship for the catchment was estimated using the power function method ($Q = aA^b$). This method is well suited for small-to-medium scale catchments. On the continental scale, other methods may be to be sought as the interplay between groundwater, evaporation, climatic zones and discharge may introduce errors beyond meaningful limits (Finlayson & Montgomery 2003). The data revealed a power function relationship of $Q = 0.1227A^{0.9785}$. Using the catchment area grids for each resolution, the power function was used to calculate discharge for each of the grid cells.

Using the long-term discharge data, a Log Pearsons III flood frequency analysis was calculated to determine the 2-year probable flood at the Gingera Station. The Gingera Station site was selected on the discharge grids and scaled to match the 2-year probable discharge value. The new grid represented a 2-year flood for each cell.

Calculation of the final stream power grid was carried out in the raster calculator function of ArcGIS 9. The specific weight of water (γ), 2-year discharge (Q) and slope (s) produces total stream power grids for the entire catchment. Longitudinal profiles were exported by clipping a stream network shapefile of the main channel. The channel shapefile was converted to a 3D surface using the 3D analysis tool in ArcGIS 9. A Visual Basic script was developed to export the 3D surface as X, Y and Z values.

RESULTS

Figure 1 shows immediately the averaging effect of the profiles extracted from the 5 and 10 m grids. Table 1 demonstrates a selection of the differences between profile results with the number of cells counted illustrating resolution differences that led to over estimates in average discharge, elevation, stream power and slope in the 5 and 10 m grids. Maximum and minimum results of the 5 and 10 m elevation grids are generally higher than the 1 m grid. However, the 5 m maximum elevation value is anomalous to this and is difficult to see graphically (Figure 2). Importantly however, the highest estimation of maximum stream power comes from the 1 m grid, which confirms the smoothing effects of the coarser grids.

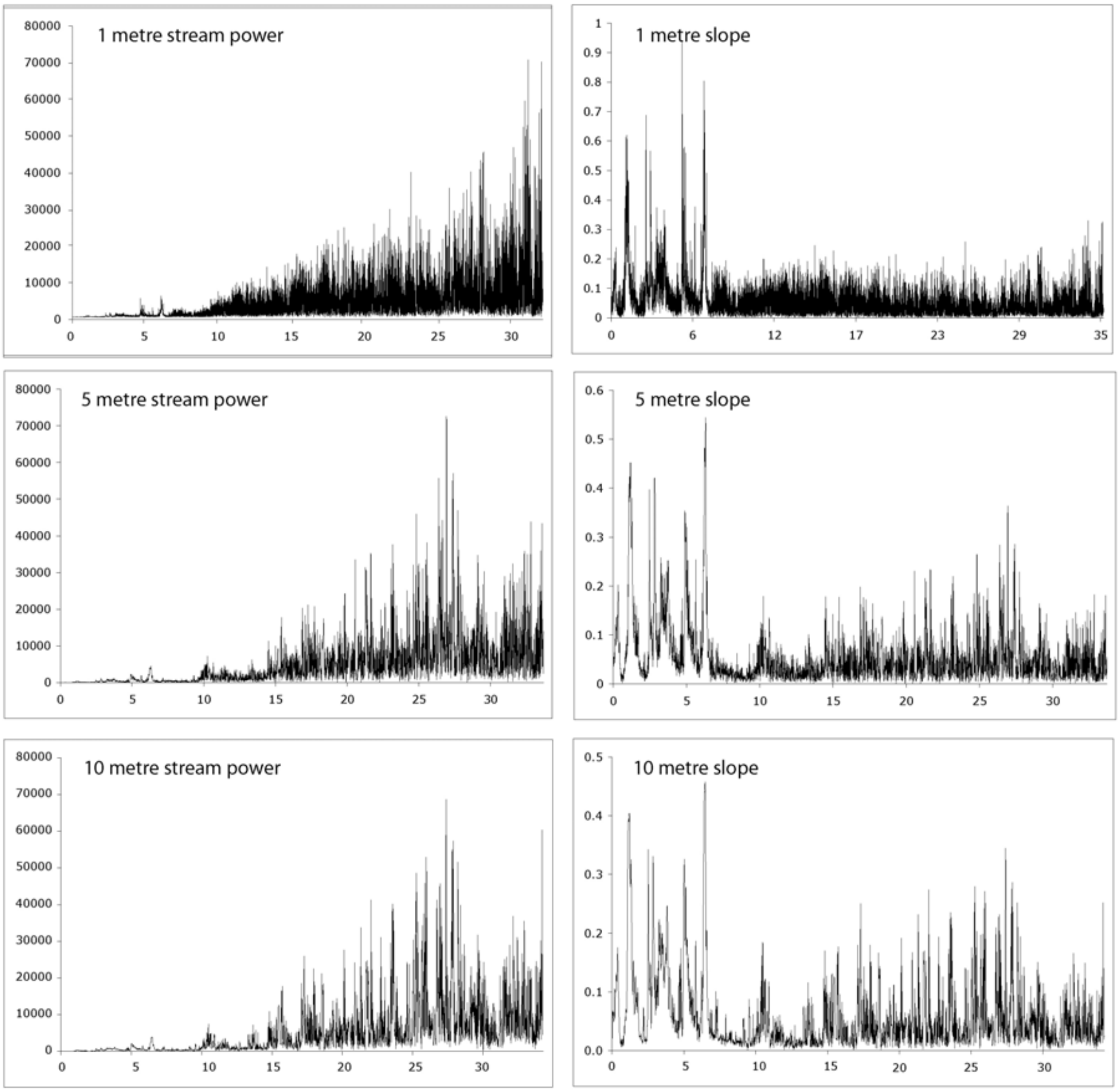

Figure 1: Downstream profiles of stream power (W m^{-1}) and slope (m/m) for the 1, 5, and 10 m grids over the 34 km reach of the Cotter River.

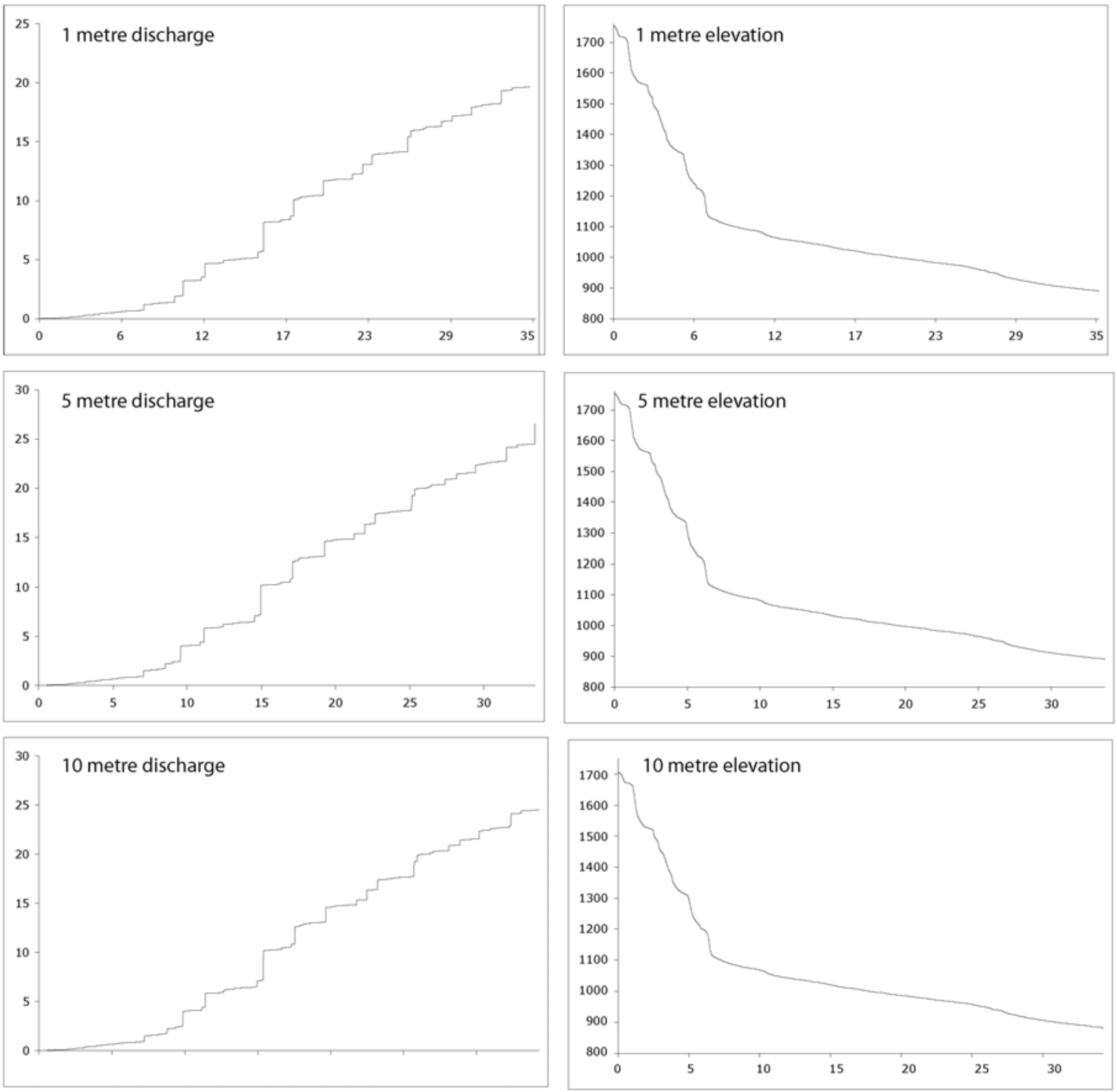

Figure 2: Downstream profiles of 2-year discharge (cumecs) and elevation (m) for the 1, 5, and 10 m grids taken from the 34 km reach of the Cotter River.

Table 1: Comparison of statistical results from the extracted profiles.

Grid resolution	Parameter	Average	Count (cells)	Minimum	Maximum
1m	Stream power (Wm^{-1})	4623	30,175	0	78943
	Slope (m/m)	0.057	30,175	0.94	0
	Elevation (m)	1086	30,175	889.61	1754.52
	Discharge (cumecs)	10.89	30,175	0.0039	26.43
5m	Stream power (Wm^{-1})	4926	4,852	0	72605
	Slope (m/m)	0.06	4,852	0.54	0.003
	Elevation (m)	1086	4,852	889.97	1753.59
	Discharge (cumecs)	10.96	4,852	0.0042	26.59
10m	Stream power (Wm^{-1})	5294	2,879	2.89	68661
	Slope (m/m)	0.057	2,879	0.45	0.001
	Elevation (m)	1086	2,879	889.96	1754.65
	Discharge (cumecs)	10.95	2,879	0.004	24.5

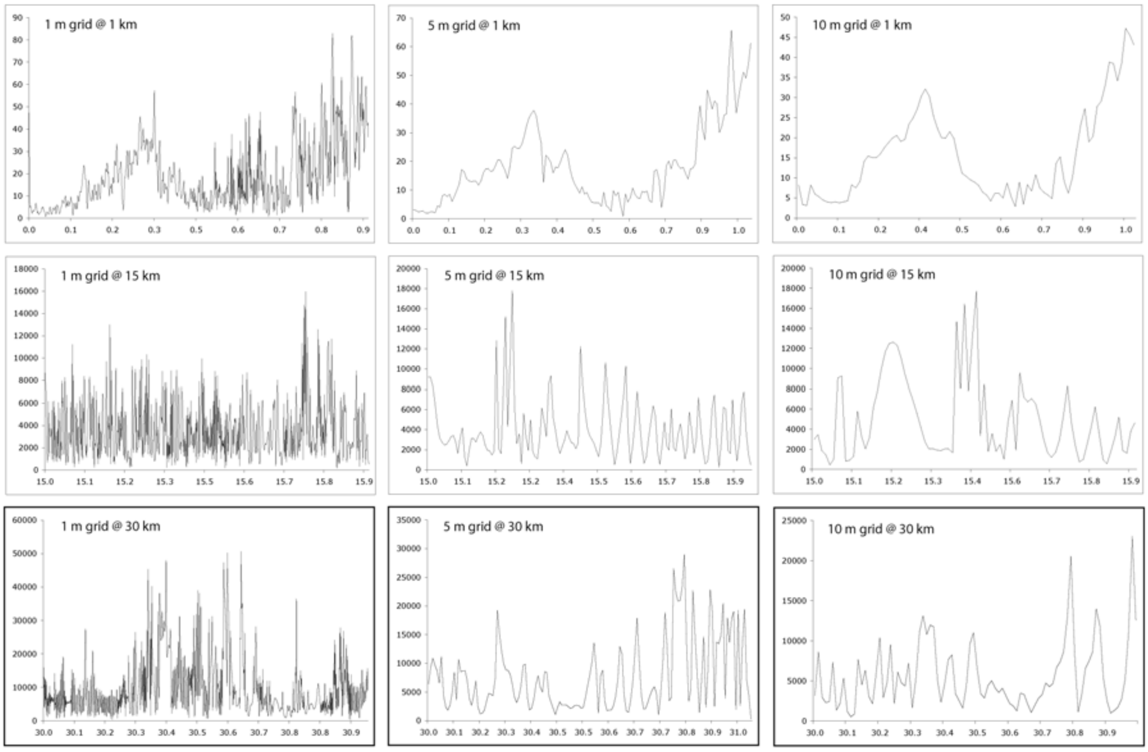

Figure 3: Stream power comparisons for stream reaches at 0 to 1 km, 15 to 16 km and 30 to 31 km.

CONCLUSION

The availability of detailed landform information and long term hydrological records in a landscape essentially free of anthropological impacts lends the upper Cotter River to a detailed investigation of underlying hydrological processes. In this investigation, specific stream power, a key determinant of fluvial processes such as stream bank erosion and sediment transport, was predicted solely on channel gradient. This would not have been possible in the absence of high-resolution landform data or without the hydrological record to validate, or refine, prediction of discharge characteristics and stream power.

Modelling of hydrodynamic stream variable at three levels of spatial resolution (1, 5 and 10 m grids) produces broadly similar results. However there are significant differences in predicted minima and maxima stream powers. These differences may be attributable to smoothing processes attendant to grid characterisation from source LiDAR data. The Cotter River results presented differ from theoretical stream distributions reported by Knighton (1999). I report no maxima, followed by exponential decay, in the mid profile for any of the different grid size profiles. This may be explained either by the fact that such maxima do not exist in small catchments or that the distribution observed by Jain *et al*. (2005) in modelling the Hunter River catchment is not applicable at this scale.

Discharge profile peaks, where low stream powers are predicted, characterise steep, low discharge upper river reaches. Headwater channels in the Cotter River closely match this profile. Here, observed sediment deposition is on channel margins, midstream, however, the slope alone controls the predominantly transport character of the river and its tributaries. Elsewhere, depositional and transport reaches behaved in a manner clearly consistent with our model predictions.

Past studies on stream power have focused on models employing long profile smoothing and curve fitting (Knighton 1999). At a local scale, stream morphology is too complex for coarse resolution smoothed models to successfully predict stream power. In such modelling, locus of change is lost. This can be illustrated in the high slope reaches of the upper Cotter River where, if using conventional modelling resulting in further smoothing of data, there would be a significant underestimation of stream power. This is consistent with my observed findings between, respectively, 1 and 10 m grids that i used to estimate stream power. This highlights the need for contiguous data at the highest possible resolution.

This paper outlines a simple, practical method for estimating stream power. High-resolution spatial data demonstrates a real and underlying complexity of fluvial processes that theoretical models, and point observations, fail to predict. With the emerging availability of high-resolution spatial data, the stream power equation can now find application at a small sub catchment scale. This enables calculation of stream power values at any point in a stream, albeit with the limitations cited. This will enable a more accurate estimation of catchment sediment yield and of erosional forces.

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